

ACTIVE REPLICA TRANSFORMER HYBRID

BACKGROUND OF THE INVENTION

**CROSS REFERENCE TO RELATED APPLICATION**

The present invention claims priority under 35 U.S.C. §119 (e) from U.S. provisional application serial no. 60/206409, entitled "Active Replica Transformer Hybrid," filed May 23, 2000, and from U.S. provisional application serial no. 60/211571, entitled "Active Replica Transformer Hybrid," filed June 15, 2000, the contents of each of which are incorporated herein by reference.

The present invention is related to the following commonly-assigned, copending application:

"Direct Drive Programmable Class A and B High Speed Power DAC", filed on even date and assigned application Serial No.

\_\_\_\_\_ (Attorney Docket No. MP0035), the contents of which are incorporated herein by reference.

(1) FIELD OF THE INVENTION

This invention relates to an active replication transmitter circuit for near end transmission cancellation and more specifically to an adjustable replication transmitter circuit with a low pass filter.

## (2) DESCRIPTION OF THE RELATED ART

Hybrids are widely used in communication systems that send and receive signals on a single pair of wires. In order to detect the signals with error free performance it is important that near end transmission from the nearby-transmitted signal be removed from the received signal. A good hybrid is defined as a hybrid that can reject most of the near end transmission signal from the desired received signal. A good hybrid is important because as the distance between two ends of a communicating/network nodes increases, the received signal strength decreases, while near end transmission signal from the nearby transmitted signal stays approximately constant. In order to detect the received signal with error free performance, it is important that any near end transmission signal from the nearby transmitted signal is removed from the receive signal.

In many conventional communications systems such as PC modems, ADSL, VDSL and the like, operating on standard twisted pair telephone wires, the two ends of the communicating nodes are isolated by one or more isolation transformers. There are two types of conventional hybrids typically used in such applications. The first is a bridge hybrid, also referred to as a resistive bridge hybrid. The second type is a hybrid transformer. For these types of applications, these hybrids generally work well because these applications do not usually utilize the low frequency range of the communications bandwidth. Another term for this is DC free signaling.

Newer communication systems, such as gigabit Ethernet (IEEE standard 802.3ab), use a non-DC free signaling. Unfortunately, conventional hybrids only work well for rejecting higher frequency near end transmission signals. Therefore, extremely complicated digital signal processing (DSP) based echo canceling technology is needed to reject not only the residual high frequency echo but also the large amplitude low frequency echo signal. This low frequency echo signal is seen by the receiver as transmitter base line wander.

U. S. Patent 4,935,919 to Hiraguchi is directed to an echo canceler in a modem, which cancels echoes from hybrid transformers on both the near end and the far end. The echo canceler has a variable delay, which may be adjusted to conform to a round trip of an echo. An adaptive filter has a number of delay circuits, each adding an increment of delay. A number of these delay circuits are selected in order to provide a selected delay time.

U. S. Patent 5,305,379 to Takeuchi, et al. describes a sending data buffer for holding sending data temporarily and transmitting the data to an echo canceler section. The data buffer is installed between a sending section and an echo canceler that is included in a subscriber line circuit of an integrated service digital network. The sending data buffer is operated in a shift register mode during a sending training mode, and operated in FIFO (first in-first out) mode during a sending/receiving training mode.

Fig. 1 shows a block diagram of a communication system

showing a near end transmitter 12 (NET), near end receiver 14 (NER), in communication with a near end hybrid 10. A wire link 16, usually a twisted wire pair, connects the near end hybrid to a far end hybrid 11 which is in communication with a far end receiver 15 (FER) and a far end transmitter 13 (FET). Desired transmission is from the near end transmitter 12 to the far end receiver 15 and from the far end transmitter 13 to the near end receiver 14. It is important to reject or attenuate near end transmission signals from the near end transmitter 12 to the near end receiver 14.

Fig. 2A shows a diagram of the near end of such a communication system having cross talk attenuation. In this arrangement, NET 12 is configured as a current source. Current generated by the current source flows through output resistor R and develops a voltage across output resistor R. Alternatively, as shown in Fig. 2B, NET 12' may be configured as a voltage source having resistors R1 and R2. In either arrangement, NET 12 (12') feeds the primary of an isolation transformer 20. The secondary of the isolation transformer 20 is connected to a twisted wire pair communication link 22, which will be connected to a far end circuit, not shown. A replication transmitter 18 is provided to attempt to eliminate near end transmission signals from transmitter 12 (12'). The output of replication transmitter 18 is subtracted from the primary of the isolation transformer 20 by subtraction circuit 24. The output of subtraction circuit 24 is provided as an input to NER 14. Thus the input NER 14 comprises the received signal and the transmitted signal less the

replication signal. In order to eliminate effectively the effects of NET 12, the voltage developed at the output of NET 12 ( $I \times R$ ) should be equal to the voltage developed by replication transmitter 18 or  $I \times R_{\text{replication}}$ . In other words,  $R_{\text{replication}}$  should be equal to  $R$ . However, due to process variations it is difficult to ensure that  $R_{\text{replication}}$  is equal to  $R$ . As a result, such a conventional arrangement does not sufficiently eliminate the effects from NET 12 (12').

#### SUMMARY OF THE INVENTION

This invention solves these problems by using a circuit with an adjustable replication transmitter and a high pass filter to provide cross talk attenuation over a wide frequency range. The adjustable replication transmitter is adjusted so that the amplitude of the voltages at the replication transmitter provides the best possible cross talk attenuation. The high pass filter compensates for the reduced load seen by the near end transmitter at very low frequencies in order to provide effective cross talk attenuation to very low frequencies. The adjustable replication transmitter and the high pass filter can be used separately or together.

According to a first aspect of the present invention, a communication circuit comprises a near end transmitter, a hybrid having an input in communication with an output of the near end transmitter, a near end replication transmitter, a high pass filter responsive to the near end replication transmitter, a

subtractor to subtract an output from the high pass filter from the output from the near end transmitter and an output of the hybrid, and a near end receiver responsive to an output of the subtractor.

According to a second aspect of the present invention, the hybrid comprises an isolation transformer.

According to a third aspect of the present invention, the hybrid comprises an active circuit.

According to a fourth aspect of the present invention, the near end replication transmitter is adjustable.

According to a fifth aspect of the present invention, the near end replication transmitter comprises a current generator connected in parallel with an adjustable load.

According to a sixth aspect of the present invention, the near end replication transmitter comprises an adjustable current generator connected in parallel with a load.

According to a seventh aspect of the present invention, an adjustable capacitive load is provided in communication with the near end replication transmitter to maximize signal delay matching between the near end transmitter and the near end replication transmitter.

According to an eighth aspect of the present invention, an adaptive control circuit is provided and is responsive to the adaptive control circuit.

According to a ninth aspect of the present invention, the high pass filter comprises an inductor having similar characteristics as the hybrid.

According to a tenth aspect of the present invention, the high pass filter comprises a combination of a resistance and a capacitance.

According to an eleventh aspect of the present invention, a communication circuit comprises a near end transmitter, a hybrid having an input in communication with an output of the near end transmitter, a near end adjustable replication transmitter, a subtractor to subtract an output from the near end adjustable replication transmitter from the output from the near end transmitter and the hybrid, and a near end receiver responsive to an output of the subtractor.

According to a twelfth aspect of the present invention, a communication circuit comprises near end transmitting means for transmitting a transmitted signal, hybrid means having an input in communication with an output of the near end transmitting means for communicating the transmitted signal to and a received

According to a thirteenth aspect of the present invention, a communication circuit comprises near end transmitting means for transmitting a transmitted signal, hybrid means having an input in communication with an output of the near end transmitting means for communicating the transmitted signal to and a received signal from a channel, near end adjustable replication transmitting means for generating an adjustable replication signal, subtracting means for subtracting the adjustable replication signal from the received signal and the transmitted signal, and near end receiving means for receiving an output of the subtracting means.

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According to a fifteenth aspect of the present invention, a communication method comprises the steps of (a) transmitting a transmitted signal, (b) combining the transmitted signal with a received signal from a channel, (c) generating a replication signal, (d) adjusting the replication signal, (e) subtracting adjusted replication signal from the transmitted and received signals, and (f) receiving an output signal from step (e).

According to a sixteenth aspect of the present invention, a communication circuit comprises a near end circuit and a far end circuit. The near end circuit comprises a near end transmitter, a near end hybrid having a first terminal in communication with an output of the near end transmitter and a second terminal, a near end replication transmitter, a near end high pass filter responsive to the near end replication transmitter, a near end subtractor to subtract an output from the near end high pass filter from the output from the near end transmitter and the near end hybrid, and a near end receiver responsive to an output of the near end subtractor. The far end circuit comprises a far end transmitter, a far end hybrid having a third terminal in communication with an output of the far end transmitter and a fourth terminal in communication with the second terminal of the near end hybrid, a far end replication transmitter, a far end high pass filter responsive to the far end replication transmitter, a far end subtractor to subtract an output from the far end high pass filter from the output from the far end

transmitter and the far end hybrid, and a far end receiver responsive to an output of the far end subtractor.

According to a seventeenth aspect of the present invention, a communication circuit comprises a near end circuit and a far end circuit. The near end circuit comprises a near end transmitter, a near end hybrid having a first terminal in communication with an output of the near end transmitter and a second terminal, a near end adjustable replication transmitter, a near end subtractor to subtract an output from the near end adjustable replication transmitter from the output from the near end transmitter and the near end hybrid, and a near end receiver responsive to an output of the near end subtractor. The far end circuit comprises a far end transmitter, a far end hybrid having a third terminal in communication with an output of the far end transmitter and fourth terminal in communication with the second terminal of the near end hybrid, a far end adjustable replication transmitter, a far end subtractor to subtract an output from the far end adjustable replication transmitter from the output from the far end transmitter and the far end hybrid, and a far end receiver responsive to an output of the far end subtractor.

According to an eighteenth aspect of the present invention, a communication circuit comprises a near end communication means and a far end communication means. The near end communication means comprises near end transmitting means for transmitting a first signal, near end hybrid means having a first terminal in communication with an output of the near end transmitting means

for communicating the first signal to and in communication with a second signal from a channel, near end replication transmitting means for transmitting a near end replication signal, near end high pass filter means for high pass filtering the near end replication signal, near end subtracting means for subtracting the near end high pass filtered replication signal from the first signal from the near end transmitting means and the second signal from the near end hybrid means, and near end receiving means for receiving an output signal from the near end subtracting means.

The far end communication means comprises far end transmitting means for transmitting the second signal, far end hybrid means having a second terminal in communication with an output of the far end transmitting means for communicating the second signal to and the first signal from the channel, far end replication transmitting means for generating a far end replication signal,

far end high pass filter means for high pass filtering the far end replication signal, subtracting means for the far end high pass filtered replication signal from the second signal from the far end transmitting means and the first signal from the far end hybrid means, and far end receiving means for receiving an output signal from the subtracting means.

According to a nineteenth aspect of the present invention, a communication circuit comprises a near end communication means and a far end communication means. The near end communication means comprises near end transmitting means for transmitting a first signal, near end hybrid means having an input in

communication with an output of the near end transmitting means for communicating the first signal to and a second signal from a channel, near end adjustable replication transmitting means for generating a near end adjustable replication signal, near end subtracting means for subtracting the near end adjustable replication signal from the first signal from the near end transmitting means and the second signal from the near end hybrid means, and near end receiving means for receiving an output of the near end subtracting means. The far end communication means comprises far end transmitting means for transmitting the second signal, far end hybrid means having an input in communication with an output of the far end transmitting means for communicating the second signal to and the first signal from the channel, far end adjustable replication transmitting means for generating a far end adjustable replication signal, far end subtracting means for subtracting the far end adjustable replication signal from the second signal from the far end transmitting means and the first signal from the far end hybrid means, and far end receiving means for receiving an output of the far end subtracting means.

According to a twentieth aspect of the present invention, a communication method comprises the steps of (a) transmitting a first signal, (b) combining the first signal with a second signal from a channel, (c) generating a first replication signal, (d) high pass filtering the first replication signal, (e) subtracting the high pass filtered first replication signal from the first

and second signals, receiving an output signal from step (e), (g)

transmitting the second signal, (h) combining the second signal with the first signal from the channel, (i) generating a second replication signal, (j) high pass filtering the second replication signal, (k) subtracting the high pass filtered second replication signal from the first and second signals, and receiving an output signal from step (k).

According to a twenty-first aspect of the present invention, a communication method comprises the steps of (a) transmitting a first signal, (b) combining the first signal with a second signal from a channel, (c) generating a first replication signal, (d) adjusting the first replication signal, (e) subtracting the adjusted first replication signal from the first and second signals, receiving an output signal from step (e), (g) transmitting the second signal, (h) combining the second signal with the first signal from the channel, (i) generating a second replication signal, (j) adjusting the second replication signal, (k) subtracting the adjusted second replication signal from the first and second signals, and (l) receiving an output signal from step (k).

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a conventional communication system.

Figs. 2A and 2B are schematic diagrams of conventional

communication systems having NET noise attenuation.

Fig. 3A and 3B are schematic diagrams of the communication system of the first embodiment of the present invention having NET attenuation provided by a replication transmitter and a low pass filter arranged between the replication transmitter and the subtraction circuit.

Fig. 4A and 4B are schematic diagrams of the communication system of the second embodiment of the present invention having NET attenuation provided by an adjustable replication transmitter and a low pass filter arranged between the replication transmitter and the subtraction circuit.

Fig. 5 is a schematic diagram of an example of an adjustable transmitter.

Fig. 6 is a schematic diagram of an example of a high pass filter.

Fig. 7 is a schematic diagram of another example of a high pass filter.

Fig. 8 is a schematic diagram of an example of a calibration circuit in accordance with the present invention.

Fig. 9 is a schematic of an example of a variable resistance used in the calibration circuit of Fig. 8.

Fig. 10 is a schematic a diagram of an example of a voltage multiplier circuit.

Fig. 11A and 11B are schematic diagrams of the communication system of a third embodiment of the present invention having NET noise attenuation provided by an adjustable replication transmitter.

Fig. 12 is a diagram of another example of an adjustable transmitter.

Fig. 13 is a schematic diagram of one of the power digital to analog converters of Fig 12.

Fig. 14 is a diagram of a further example of an adjustable transmitter.

Fig. 15 is a schematic diagram of one of the power digital to analog converters of Fig 14.

Fig. 16 is a diagram of an additional example of an adjustable transmitter.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

Refer now to Figs. 3A-16 for a description of the preferred embodiments of this invention.

A first embodiment of the communication system of this invention is shown in Figs. 3A and 3B. The present invention is preferably implemented in an Ethernet transceiver operating at 1000Mbps/sec. As shown therein, near end transmitter 12 feeds the primary of an isolation transformer 20. The secondary of the isolation transformer 20 is connected to a twisted wire pair 22, which is connected to a far end circuit, not shown. The primary of the isolation transformer 20 is also fed to subtraction circuit 24, and an output of subtraction circuit 24 is input to near end receiver 14. In this embodiment a replication transmitter 130 is provided to compensate for the effects of near end transmitter 12 as another input to subtraction circuit 24. A high pass filter 32 is further provided between replication transmitter 30 and subtraction circuit 24. The high pass filter compensates for the decreased load seen by the near end transmitter 12 at lower frequencies.

Figs. 6 and 7 show two circuits for realizing the high pass filter 32. The circuit of Fig. 6 shows an RC network having a first capacitor 60 connected between the first input 40 and first output 42, a second capacitor 62 connected between the second input 41 and second output 43, and a resistor 64 connected between the first output 42 and the second output 43. The filter of Fig. 6 reduces the amount of the voltages from the replication transmitter reaching the subtraction network at lower frequencies.



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The circuit of Fig. 7 illustrates a high pass filter implemented as an inductor 70. The inductor 70 places a load which decreases at decreasing frequencies between the first output and second output of the replication transmitter which reduces the amount of the voltages from the replication transmitter reaching the subtraction network at lower frequencies. The circuit of Fig. 7 has the added advantage that the inductor 70 can be chosen to match the inductance of the primary of the isolation transformer seen by the outputs of the near end transmitter. The inductor will simulate the DC wander behavior of NET 12. Alternatively, inductor 70 can be implemented by isolation transformer having the same characteristics of isolation transformer 20. However, this implementation is somewhat more costly than the matching inductor.

In such an arrangement, any DC components of the transmit signal exists in the replica path signal. By using this replica, a much simpler digital signal processor (DSP) based echo canceler may be employed to cancel any residual echo that is not cancelled.

A second embodiment of the communication method of this invention is shown in Figs. 4A and 4B. The second embodiment, is similar to the first embodiment and replication transmitter 30 comprises an adjustable gain control to maximize the amplitude matching between the main signal path and the replica signal path.

Figs. 11A and 11B illustrate a third embodiment which

is similar to the second embodiment, except that the high pass filter is omitted.

A circuit which can be used to realize adjustable replication transmitter 30 is shown in Fig. 5. The replication transmitter comprises a current source 50, connected in parallel with a load 52. Either current source 50, load or resistor 52, or both can be varied to produce the adjustable voltages at the output thereof.

Fig. 8 illustrates an example of a circuit to adjust or calibrate resistor R 52 to match output resistor R. As noted above one way to adjust the output of replication transmitter 30 to match the output NET 12 is to calibrate  $R_{\text{replication}}$  52 such that  $R_{\text{replication}}$  52 is substantial equal to R. This can be accomplished by providing an external resistor  $R_{\text{ext}}$  which has the same value as the output resistor R. As shown in Fig. 8, the voltage developed across  $R_{\text{ext}}$  is compared to  $R_{\text{replication}}$  by comparator 65.  $R_{\text{replication}}$  is adjusted until the voltages across  $R_{\text{ext}}$  and  $R_{\text{replication}}$  are substantially equal. Fig. 9 illustrates an example of an adjustable or variable resistance comprising n switchable resistances  $R_{x1}$  through  $R_{xn}$  which are switched by respective switches  $S_1$  through  $S_n$ , in response to comparator 65. The calibration or adjustment of  $R_{\text{replication}}$  can be conducted upon startup, continuously, on a timed basis or upon a manual request.

Fig. 9 illustrates another arrangement in which the output voltage of replication transmitter is adjusted by voltage multiplier 200. As is known by one of ordinary skill in the art,  $V'_{\text{rep}} = V_{\text{rep}} R_{F2}/R_{F1}$ . In this arrangement, the output of

comparator 65 is used to adjust or calibrate either one or both of  $R_{F2}$  and  $R_{F1}$ .  $R_{F2}$  and  $R_{F1}$  can be implemented for example, as shown in Fig. 9.

Fig. 12 is another implementation of replication transmitter 30. Fig. 12 illustrates a transmitter comprising  $n$  direct drive programmable high speed power digital to analog converters  $400_1-400_n$ . A complete description of such is provided in commonly assigned, copending application "Direct Drive Programmable Class A and B High Speed Power DAC", filed on even date and assigned application Serial No. \_\_\_\_\_ (Attorney Docket No. MP0035), the contents of which are incorporated herein by reference. In accordance with IEEE standard 802.3ab the transmitter provides 17 different levels which is accomplished by superpositioning selected ones of the direct drive programmable high speed power digital to analog converters  $400_1-400_n$ . In this arrangement the replication transmitter comprises current sources  $I_1...I_n$  configured in series to develop an output voltage across  $R_{\text{replication}}$ . In this arrangement,  $R_{\text{replication}}$  may be adjustable similarly as described above. Alternatively,  $R_{\text{replication}}$  may be fixed and the output voltage may be multiplied by a voltage multiplier similar to that of voltage multiplier 200. Fig. 13 shows the details of one of the direct drive programmable high speed power digital to analog converters  $400_i$  and a detailed explanation of which can be found in the aforementioned commonly-assigned application.

Fig. 14 and 15 shown another embodiment which is a simplification to that in Figs. 11 and 12. The inventor has observed that a replication voltage for each DAC is developed

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across each resistor  $R_k$ . Accordingly, the voltages developed can be summed by summing circuit 700. It is noted that resistor  $R_f$  is adjustable as in the previous embodiments. Fig 16, illustrates a variant to Fig. 15, instead of calibrating feedback resistor  $R_k$ , the output voltage is multiplied by multiplier 200 as described above.

As a further variation to the preceding embodiments, it is proposed to provide an adjustable capacitive loading in the replica signal path to maximize the signal delay matching between the main signal path and the replica signal path. The main signal path does not see any changes as a result of adjusting replication transmitter 30, since replication transmitter 30 is not connected to the main signal path..

Adjustable replication transmitter may include an adaptive circuit for adjusting the capacitive loading to maximize the signal delay matching between the main signal path and the replica signal path.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made without departing from the spirit and scope of the invention. It is well within the scope of one of ordinary skill in the art to implement any of the functional circuits described herein. More specifically while the hybrid of the present embodiment is illustrated as an isolation transformer; one skilled in the art would appreciate an active

